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**DOI: 10.24406/h-457468**

**Extract from:**
**ICNAP Study Report 2023**
**International Center for Networked, Adaptive Production, Aachen**
**DOI: 10.24406/publica-2114**

# Realizing Plug-and-Produce on the Shopfloor

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# Introduction

Due to the increased demand for customized products and rising customer expectations, the manufacturing industry has experienced higher product variety and shorter product life cycles. The trend of mass customization pressures companies to put a greater emphasis on the flexibility and adaptability of the entire production chain. However, current production lines are not easily adaptable to manufacture new product variants or take advantage of new production capabilities. It requires a significant amount of manual work, which is expensive. As a result, production facilities tend to be static, and owners are hesitant to embrace innovation and make process changes. [20, 21]

In the manufacturing industry, the concept of Plug-and-Produce is defined as: [22]

"The capability of a production system to automatically identify a new or modified component and to integrate it correctly into the running production process without manual efforts and changes within the design or implementation of the remaining production system."

This concept aims to simplify and streamline the integration of new equipment or systems into existing production processes. It involves the use of standardized interfaces and protocols, allowing different machines and devices to easily connect and communicate with each other. This plug-and-play approach enables manufacturers to add new components quickly and effortlessly or upgrade existing ones without extensive reconfiguration or programming. The goal is to enhance flexibility, efficiency, and interoperability in the manufacturing environment. [20, 21]

Plug-and-Produce has the potential to bring significant cost savings for manufacturing companies as highlighted in Figure 27. By providing the capability to easily add or remove equipment or devices from the production process, Plug-and-Produce helps in reducing downtime caused by equipment failures or maintenance. This seamless integration ensures that production can continue smoothly without prolonged disruptions. Moreover, Plug-and-Produce enables companies to scale up or down their production as needed. The ability to quickly adjust the equipment allows for a more agile response to changes in market demand. By efficiently adapting to fluctuations in production requirements, companies can avoid overproduction or underutilization of resources, leading to cost savings. By facilitating the integration of sensors and other monitoring devices gathering data on the production process, it improves quality control and transparency. Another crucial aspect of Plug-and-Produce is the automation of data flow and communication between equipment and devices. This automation minimizes manual efforts and errors, resulting in increased productivity. This ultimately leads to improved overall production efficiency. [23]

The implementation of Plug-and-Produce in the manufacturing industry faces several challenges that hinder its widespread adoption as shown in Figure 27. One of the primary challenges is the lack of standardization across manufacturing processes and equipment and the absence of standardized interfaces and protocols. Accordingly, each integration requires custom development and configuration, resulting in additional time and costs. The absence of global and industry-wide standards limits the interoperability between equipment differing in vendors, type, or age. This makes it difficult for manufacturers to switch

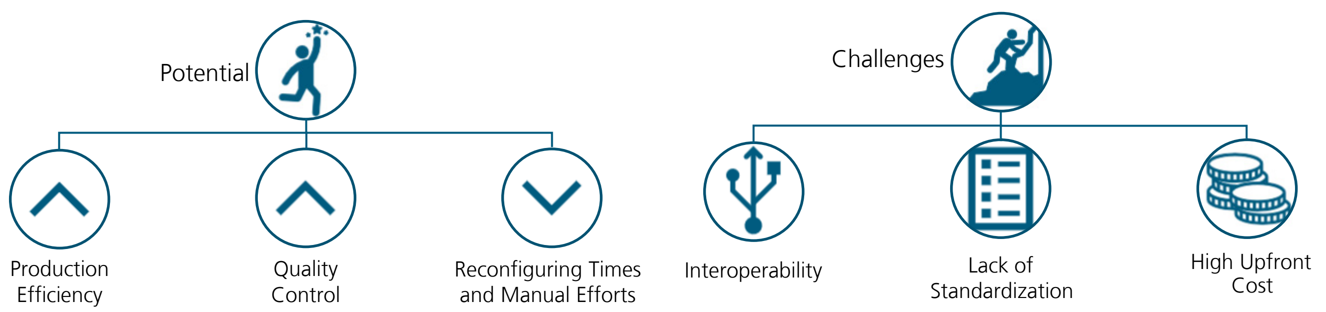


*Figure 27: Potential and challenges of Plug-and-Produce in the manufacturing industry*

between different suppliers or upgrade their systems without significant reconfigurations. High upfront costs present another challenge for Plug-and-Produce implementation. The initial investment required to adopt the necessary automation technologies and upgrade existing systems can be substantial. This financial burden may deter some manufacturers from embracing Plug-and-Produce, especially for smaller companies with limited resources. Addressing these challenges will be crucial for the successful implementation of Plug-and-Produce in the manufacturing industry. [23]

In the ICNAP study "Realizing Plug-and-Produce on the shopfloor" the goal is to explore the topic of Plug-and-Produce in the context of the adaptable factory for the manufacturing industry. Starting with the state of the art of implementing Plug-and-Produce, its current understanding and use is described in the following report. The concept of interoperability is introduced to distinguish between different levels of interoperability. Furthermore, the analysis of use cases, which have been identified in the literature as well as in the ICNAP community, show the potential of implementing Plug-and-Produce. To provide a direct entry point into the use of Plug-and-Produce a prototypical implementation is shown within this study. In the end, the study is summarized, and an outlook is given.

# Plug-and-Produce for industrial manufacturing

## Adaptable factory

The concept of the adaptable factory defined by the "Plattform Industrie 4.0" [21] refers to a manufacturing facility that can be quickly and, in some cases, fully automatedly to accommodate changes in production capacities and capabilities. The essential element for successful implementation is a modular design that allows for easy reconfiguration within the factory. Intelligent and interoperable modules can adapt to new configurations independently, and standardized interfaces between modules enable swift and straightforward adjustments to meet market and customer demands. [21]

## Interoperability

To implement the adaptable factory, the hardware and software components used must be interoperable. Interoperability, in the field of computer science, refers to the "degree to which two or more systems, products, and components can exchange information and use the exchanged information". [24] However, achieving this information exchange is a real challenge due to the diversity of assets, products, and systems used in production. Interoperability can be divided into four consecutive levels, as shown in Figure 28. [25]

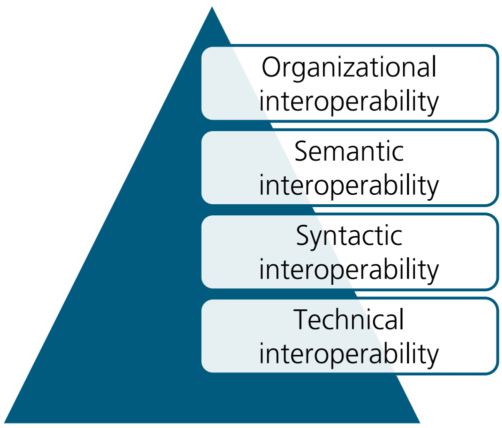


*Figure 28: The four levels of interoperability. [25]*

The four levels are defined as: [25]

- Organizational interoperability refers to the ability of organizations or systems to work together in an effective and coordinated manner. This includes the coordination of processes, business rules, and other organizational aspects to ensure that systems not only exchange data, but also work together in accordance with organizational goals and requirements.

- Semantic interoperability goes beyond ensuring that the meaning of the data exchanged between systems is understood and correctly interpreted. This often requires the use of ontologies or standardized vocabularies to ensure that both systems have the same meaning or interpretation of the data.
- Syntactic interoperability ensures that data is transferred between systems in a common format that is understood by both systems. Standards or common data formats are often used to ensure that the transferred data is structured in a consistent and predictable way.
- Technical interoperability refers to the ability of two or more systems to exchange data, regardless of the meaning or context of the data. Aspects such as connection establishment, data transmission and communication protocols are considered.

Especially older machines and devices only cover technical and syntactic interoperability. Therefore, it can be of interest to develop a new interface for these assets to gain semantic interoperability by implementing studentized information models. Using OPC UA (Open Platform Communications Unified Architecture)  as framework, enables organizational interoperability because it provides functionalities to handle access rights, etc.

## Relevant standards: OPC UA and Umati

OPC UA is a standard for industrial communication and interoperability. It provides a secure and reliable means of exchanging data between different devices and systems in the industrial automation domain. OPC UA offers a scalable and flexible framework that enables seamless integration of various equipment, machines, and software applications. [26]

The OPC 40001 UA for Machinery standard, published by the German Machine Tool Builders' Association, Verband Deutscher Maschinen- und Anlagenbau (VDMA), is an extension of OPC UA specifically designed for machinery in the manufacturing industry. It is part of the universal machine technology interface (Umati) which defines a set of standardized information models and communication protocols that enable machinery to provide data and interact with other systems in a consistent and interoperable manner. This standard ensures that machinery from different manufacturers can communicate and be integrated more easily. [27]

Similarly, the OPC 40010 UA for Robotics standard, also published by the German Machine Tool Builders' Association, focuses on the integration of robotic systems. It defines a standardized information model and communication protocols to enable seamless communication and control of robots within the industrial automation environment. This standard ensures interoperability between robot systems from different manufacturers, allowing for easy integration and coordination with other devices and systems. [27]

Both standards, OPC 40001 UA for Machinery and OPC 40010 UA for Robotics, contribute to the overall goal of enabling interoperability and facilitating the integration of machinery and robotic systems into industrial automation environments.

## Plug-and-Produce concept

To implement Plug-and-Produce functionality into production equipment, it is necessary to identify and automate all essential steps for a full integration of unknown assets into an existing production network. Based on the concept suggested by the "Plattform Industrie 4.0" a six-step model shown in Figure 29 has been defined. All six steps must be passed during the integration of a new asset into the production network: (1) physical connection, (2) discovery, (3) basic communication, (4) capability assessment, (5) configuration and (6) integration. [20]

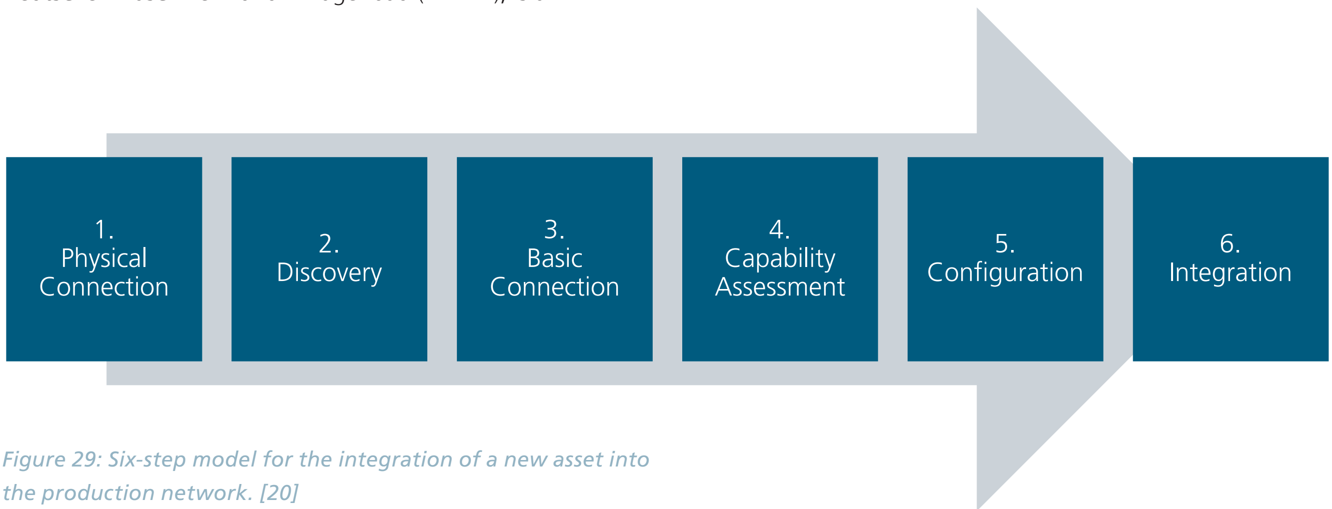


*Figure 29: Six-step model for the integration of a new asset into the production network. [20]*

These steps contain the following details: [20]

**(1)** Physical connection: This step involves physically connecting the new asset to the existing production network. It includes tasks such as plugging in cables, connecting devices, and ensuring proper power supply.
**(2)** Discovery: In this step, the existing production network identifies the new asset and recognizes its presence. This may involve network scanning or broadcasting to discover devices and their available services.
**(3)** Basic communication: Once the new asset is discovered, basic communication is established between the asset and the production network. This step involves setting up a communication protocol or interface that allows the exchange of data and information.
**(4)** Capability assessment: The production network assesses the capabilities and features of the new asset. This step involves evaluating the asset's functionality, compatibility, and performance to determine its potential integration into the network.
**(5)** Configuration: After assessing the capabilities of the new asset, the production network configures it according to the specific requirements and settings of the network. This may include adjusting parameters, assigning roles, or defining access rights.
**(6)** Integration: The final step involves fully integrating the new asset into the production network. This includes ensuring seamless interoperability with existing assets, synchronization of operations, and updating the network configuration if necessary.

# Plug-and-Produce use cases

In an adaptable factory, the production modules would have a self-description that is machine-readable and clearly defines their properties and capabilities. This allows for the (semi-) automatic integration of the production modules to accomplish a production objective, potentially reducing the amount of manual work. In their working paper concerning the topic of Plug-and-Produce, "Plattform Industrie 4.0" [20] names examples that showcase the application scenario of an adaptable factory:

- Plug-and-Produce for individual field devices for basic operation
- Plug-and-Produce for individual field devices with skills negotiation
- Plug-and-Produce for production modules using NAMUR Module Type Package (MTP)
- Plug-and-Produce for control systems/ MES managing self-contained production resources
- Plug-and-Produce for autonomous work pieces initiating their own production

We now describe two use case in more detail because existing standards already cover most aspects of it. Furthermore, they were chosen due to their higher relevance for the ICNAP community members.

### Plug-and-Produce for field devices

In their working paper about the topic of Plug-and-Produce, "Plattform Industrie 4.0" described and analyzed in detail the use case "Plug-and-Produce for field devices". A new field device is automatically connected to the network and made visible in the system. When an older field device is replaced, the new device can import the settings of the old device to minimize configuration efforts. Any changes made to the control system in the production facility are detected and updated in all related systems. The production facilities can generate new visualizations for a Manufacturing Execution System (MES). For the example realization and implementation, they use OPC UA and the Field Device Integration standard. [20, 28]

### Plug-and-Produce for control systems managing self-contained production resources

A control system managing self-contained production resources refers to a system that controls and coordinates the operation of production resources, such as robots, machines, or other assets. In agreement with the members of the ICNAP community, the second last use case (Plug-and-Produce for Control Systems Managing Self-contained Production Resources) was chosen to be described in detail and implemented as proof of concept.

For its implementation, the control software COPE [29] and a UR5 robot [30] are used. The software COPE is developed by the Fraunhofer IPT. Due to its service-oriented architecture, it is well suited for the flexible integration and control of production resources providing functionalities as services. For better understandability, the use case is divided into the two sub-use cases: (1) Discovery and Basic Connection and (2) Capability Assessment and Configuration.

Discovery and Basic Connection: According to the previous use case, the robot is physically connected to the production system and started. COPE needs to discover it, establish a basic communication and exchange of information.

Capability Assessment and Configuration: The robot provides information about its available services such as an operation for an initialization, taking and putting materials, etc. Thus, the user can start those services in COPE and get feedback during the execution. The implementation of the use case is presented in detail in the following chapter.

# Implementation

In the following, the implementation of the in Section 3.2 described use case is explained. To implement the planned interface and OPC UA information model, a suitable class library is required that enables the creation of OPC UA servers and OPC UA clients. Since the implementation is done using the .NET Framework and the C# programming language, one possible solution that meets these requirements is the OPC UA Software Development Kit from Traeger [31]. The SDK consists of a core, a client, and a server API.

To avoid the control software COPE from having to search specifically for every available OPC UA server on the network, it is beneficial to set up a master server that collects all information about the currently active OPC UA servers and forwards all data to the control software. For this scenario, the OPC Foundation provides a local Discovery Server (DS) [32] that can be used.

As depicted in Figure 30 (steps 1-5), COPE automatically discovers the new asset and establishes the communication via a OPC UA DS. A DS has the standard port 4840 and can be discovered by OPC UA servers on the respective host. Step 1: The robot connects to the network and its OPC UA server registers in the DS's server list. The list manages all servers on the respective host that are currently online. If a server does not re-register with the DS within a time interval, it will be removed from the internal list of online servers. Steps 2-5: COPE uses an OPC UA client to query the DS for the list of registered servers, including their respective Discovery URLs. A Discovery URL provides all the necessary information that a client needs to connect to a server's endpoints, enabling a secure connection between COPE and the robot.

Step 6: After establishing a secure connection, the robot exchanges its basic self-describing information with COPE as shown in Figure 30. OPC UA supports document transfer through the OPC UA server. The robot’s OPC UA server provides an XML file containing all needed information about parameters and services provided by the robot. Once COPE has access to the robot’s information, it checks whether it has gone online for the first time or reconnected. Accordingly, a new object is created or an old one updated in the control software. Step 7: The robot notifies the control software of any changes in its status through the communication node of the OPC UA information model. COPE receives these status changes via push notifications.

As shown in Figure 31 (steps 1-5), the robot provides all information about its services and enables COPE to execute those functionalities. Step 1: The robot’s OPC UA server provides an XML file containing all needed information describing its provided services. Steps 2-4: When a service of the robot should be executed, COPE first sets the necessary parameters, which are then sent to the robot via push notifications. Then, COPE calls the corresponding OPC UA method node of the corresponding service. This method invocation triggers the robot’s software module responsible for reading all the previously transmitted parameters and executing the necessary program steps performing the service. Step 5: If results are available after the service is completed, they are sent to the control software by transmitting any value changes through push notifications and processes them accordingly.

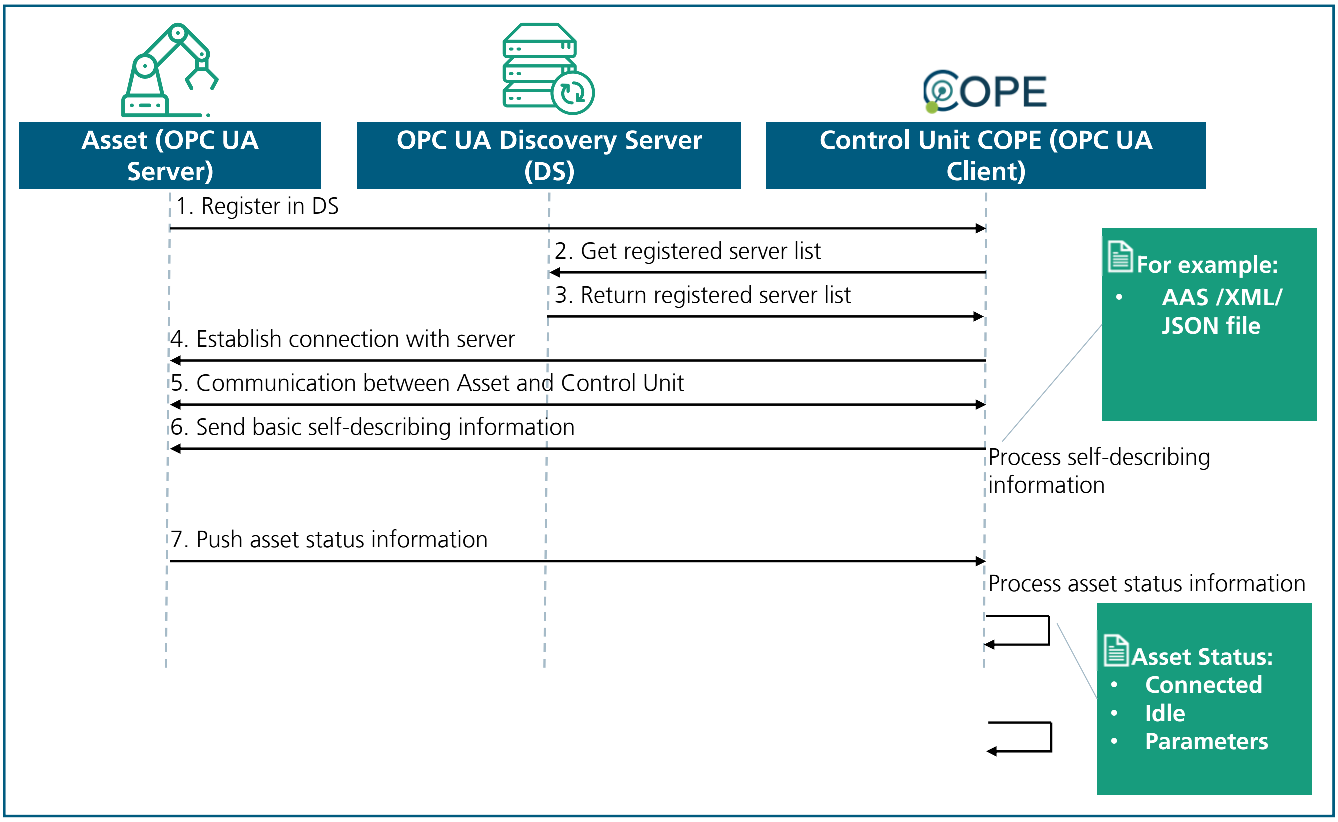


*Figure 30: Implementation of discovery and basic connection using the control software COPE and a UR5 robot.*

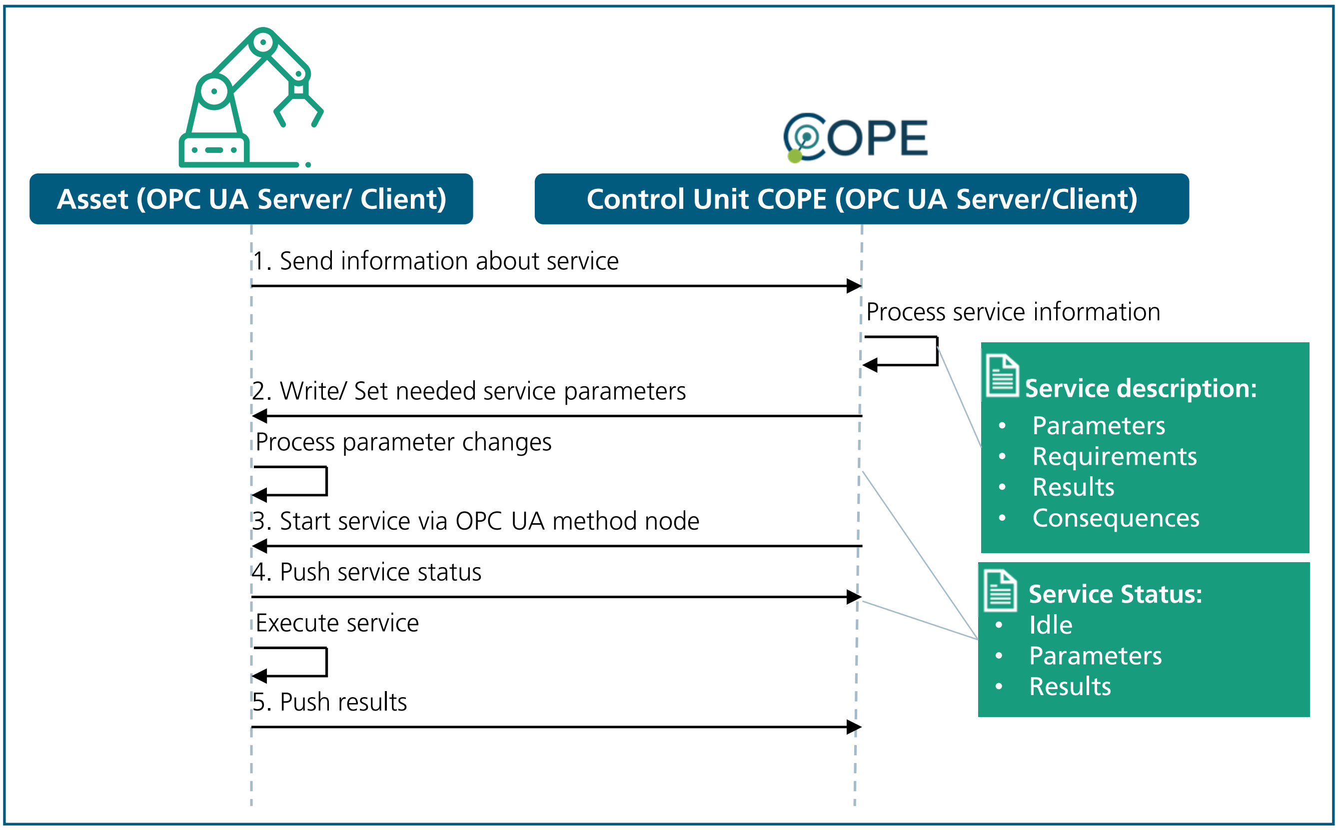


*Figure 31: Implementation of capability assessment and configuration using the control software COPE and a UR5 robot.*

# Conclusion

The study at hand gave an overview of the topic Plug-and-Produce in the context of the manufacturing industry. We can state that Plug-and-Produce has the potential to bring significant cost savings for manufacturing companies by increasing production efficiency and reducing reconfiguring times and manual effort. However, the concept suffers from a lack of standardization across manufacturing processes and equipment and the absence of standardized interfaces and protocols, especially in brown field environments and standardization.

Furthermore, multiple use cases were introduced and the use case "Plug-and-Produce for Control Systems Managing Self-contained Production Resources" was chosen for a deeper analysis and prototypical implementation. The implementation of Plug-and-Produce could be demonstrated for a bot and the control software COPE of the Fraunhofer IPT. The selected use case should be seen as a starting point and was chosen because existing standards already addressed most aspects of it. However, it does not encompass the entire concept of the adaptable factory, but it potentially provides reusable concepts for comparable use cases. Join the ICNAP community and let us explore your use cases to realize the vision of the adaptable factory together.

The long-term vision is to achieve a vendor-agnostic Plug-and-Produce solution for industrial devices, fully compliant with Industry 4.0 standards. This would greatly support plant and factory owners by reducing times for set-up and enhancing overall flexibility compared to the current state.

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